MULTISTAGE FLASH EVAPORATOR SPECIFIC ENERGY CONSUMPTION IN A DUAL PURPOSE PLANT

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ABSTRACT

The determination of the cost of the products(e.g.electricity and water)from a dual purpose installation is an important and difficult problem. The main difficulty comes from the fact that there are no absolute criteria for this determination.In this paper an attempt is carried out to study the specific energy consumption per ton of fresh water for an MSF plant(Multistage Flash Evaporator) operating on back pressure turbine concept and as a unit utilizing bleed steam extraction.The study indicated that back pressure turbine scheme is better for base load plant,while the bleed steam extraction combination is more flexible in part load operation. Simple thermodynamic relations are used to study the effect of changing the water demand and the top brine temperature (TBT) on the specific energy consumption per ton of product water. The specific energy cost of product water in a typical design of dual purpose plants is calculated for each scheme using a recirculation type MSF. In the calculations ,it is assumed that the energy consumed in an MSF is compensated by additional fuel supplied to the boiler.The cost of energy consumed by recirculation pumps and air ejectors are taken into consideration.

Keywords: Water desalination, Multistage flash, Energy Consumption.

INTRODUCTION

With raising costs and decreasing supply,the energy consumed by a desalination plant has taken an increased importance in optimization studies.One of the ways to save energy is the use of dual purpose plants for power production and water desalination.In a dual purpose plant,substantial energy savings can be achieved by the use of extracted steam from a steam turbine to heat the brine [1,2].

The maximum brine temperature in a distillation plant is limited by economic means of scale control.On the other hand, the generating costs of electric power plants are lowest when the steam is produced at higher temperatures.Early studies proved the thermodynamic and economic advantages of dual purpose plants [3-5]. Recently,studies based on the second law of thermodynamics showed that about 60% of thermal energy required for MSF plants may be saved in case of dual purpose plants using steam turbines [6]. Moreover,cheaper water may be produced in plants using waste heat from gas turbines [7].

The water cost in a dual purpose plant is strongly affected by the method of desalination as well as the water to power ratio.This ratio is changeable to give enough flexibility to both power and water demands.Researchers concerned in the economics of desalted water investigated the costs of water produced by different desalting methods [8-11].

For dual purpose plants ,both water and power costs are optimized.Studies for optimization of dual purpose plants include the water to power ratio [12,13],the temperature of exhaust steam extracted for desalination [14] or the use of hybrid systems for desalination which increase the flexibility of the plant [15,16].

In the present work, the specific energy consumption for changeable water demand is investigated for both the back pressure turbine and the condensing turbine schemes in a dual purpose plant.The effects of changing the water demand and the top brine temperature on the specific energy consumption and the product water energy cost are studied for each scheme through a typical design of dual purpose plants.

Governing Equations

The thermal energy consumed in MSF to produce a certain amount of desalted water m_d from a dual purpose plant is calculated as;

$$Q_t = m_s (h_e - h_c) (1.04)$$

$$Q_t = m_d/R(h_e - h_c) (1.04) \quad (1)$$

Noting that 4% of the thermal energy added to allow for steam jet air ejectors[8]. The enthalpy of extracted steam (h_e) depends on TBT in the MSF plant. Also,the gain ratio ,R, is optimized up to the fuel cost [17].

The electrical power is needed to operate the pumps of the MSF. The major part of the pumping power is used to recirculate the brine,m_r. The required pumping power(Q_p) is calculated from the relation :

$$Q_p = \frac{m_r.\Delta P}{\rho \eta_h.\eta_m}(1.4) \quad (2)$$

where ΔP is the pressure drop in the brine recirculation pump and the factor (1.4) is used to account for the power consumed in other pumps and auxiliaries of the MSF as estimated from the literature[8,17].Noting that the recirculation brine flow rate is changed to follow the water demand.

Thus the total energy required to operate the MSF is:

$$Q = Q_t + Q_p/\eta_p \quad (3)$$

where η_p is the overall electrical generation efficiency.

The specific energy consumption can be calculated from equation (3) as

specific energy consumption= Q/m_d.

The energy Q is equivalent to a certain reduction in the electrical output of the plant.This reduction is compensated by increasing the steam flow to the turbine,this increase is approximately:

$$\Delta S = Q/\ \eta_T(h_b - h_e) \quad (4)$$

The fuel supply to the boiler is increased by an amount G to produce ΔS , where:

$$G = \frac{\Delta S(h_b - h_f)}{\eta_b.(HHV)} \quad (5)$$

The price of the fuel G represents the energy cost of desalted water. Thus ,the specific energy cost of water can be calculated as:

$$G.FC/m_d \ (\$/t).$$

When m_d is changed to satisfy the water demand, m_s will be constant in the case of a back pressure turbine scheme but can be changed in a condensing turbine scheme. The enthalpy of extracted steam is controlled by the operation temperature T_s. In the present work T_s = TBT + 8°C. The difference between T_s and TBT depends on the heat transfer surface in the brine heater [6].

Sample Calculations

In a sample calculations ,a typical design of dual purpose plants is used to illustrate the effect of operation conditions of the MSF.

The main data used in the study are the following:

Pressure of steam at the boiler outlet	88 bar
Temperature of steam at the boiler outlet	500°C
Pressure of steam at the condenser inlet	0.05 bar
Pressure drop in the brine recirculation pump	4.1 bar
Enthalpy of feed water	1317 kJ/kg
Density of recirculated brine	1030 kg/m^3
Fuel price (heavy oil)	15 $/barrel
High heating value	40000 kJ/kg
Fuel density	900 kg/m^3
Electrical energy cost	4.1 C/kWh
Overall electrical generation efficiency	0.35
Turbine efficiency	0.8
Boiler efficiency	0.85
Brine recirculation pump hydraulic efficiency	0.8
Brine recirculation pump mechanical efficiency	0.95

To study the effect of operation conditions of MSF,two cases are investigated. Namely Case A and Case B in which the operating steam temperatures are 120 C and 98°C respectively. The data used for each case are:

	case A	case B
Water production rate,t/h	980	794
Operating steam temperature, °C	120	98
Top brine temperature, °C	112	90
Gain ratio	8	7.35
Brine recirculation ratio	9.5	12.6

The condensing turbine and the back pressure turbine schemes are shown in Figure (1.a,b).The flow schematic of a recirculation type MSF is shown in Figure (2).

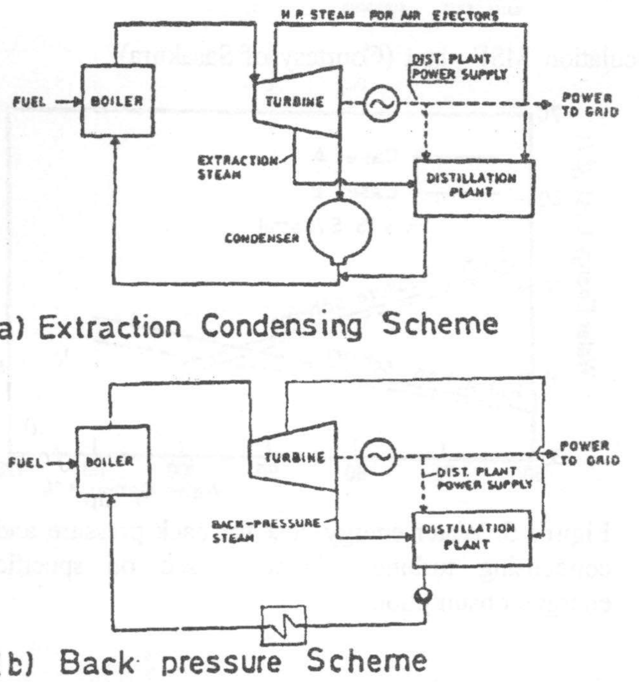

Figure 1. Dual purpose plant schemes.

The specific energy consumptions for each scheme are calculated for cases A and B.The difference in the specific energy consumption due to change of TBT is rather small.However,it is considerable for high capacities.The sensitivity of specific energy consumption to water demand is much larger in case of the back pressure turbine scheme than the condensing turbine scheme.This clear from the calculation procedure hence the back pressure steam is totally consumed in the MSF for any production rate of desalted water.

As shown on Figures (3,4), the specific energy consumption in the back pressure scheme is more than that in condensing turbine scheme except when the water demand exceeds 95% of the design value.However,the energy saving by a back pressure scheme for 100% water demand is about 6%. The thermal energy consumed per ton of product at full capacity is about 36 kWh/t(about 12.6 kWhe/t) for condensing turbine scheme and about 34 kWh/t(about 11.9kWhe/t) for back pressure scheme. These results differs only by 10% than that in the literature of similar cases [6,18]. For example, in the calculations of Darwish[6], the specific energy consumption for water desalting in a dual purpose plant ranges from 11.8 to 12.7 kWhe/t of desalted water. Other calculations for a dual purpose plant of smaller capacity [18] show that the specific energy consumption is 13.4 kWhe/t.

The water energy cost is shown on Figure (5). This cost depends on the fuel price .For the current prices of oil ,the cost of thermal energy is about 1.2 C/kWh.This value leads to water energy cost of about 40-42 C/t at the full capacity of the MSF.The extraction-condensing scheme is advantageous except for water demand >95.0 of the full capacity.The increase of the water demand from 100% to 110% using extraction scheme will increase the specific energy cost by only 1 C/t.

The power loss due to operation of the MSF is shown on Figure (6). This loss is almost constant in the case of a back pressure scheme hence a decrease of the water demand from 100% to 70% will decrease the power loss by 1 MWe. For condensing turbine scheme,the loss is almost proportional to the water demand. The condensing turbine scheme has the advantage of increasing the water production to more than 100% depending on the design of the MSF.

CONCLUSIONS

1. The specific energy consumption and the water energy cost of the MSF is less for the condensing turbine scheme than that of back pressure scheme for water demand <95% of design value.
2. The flexibility of the power plant is much more in case of condensing turbine scheme, hence the water demand can be changed within wide range without considerable increase of water cost.

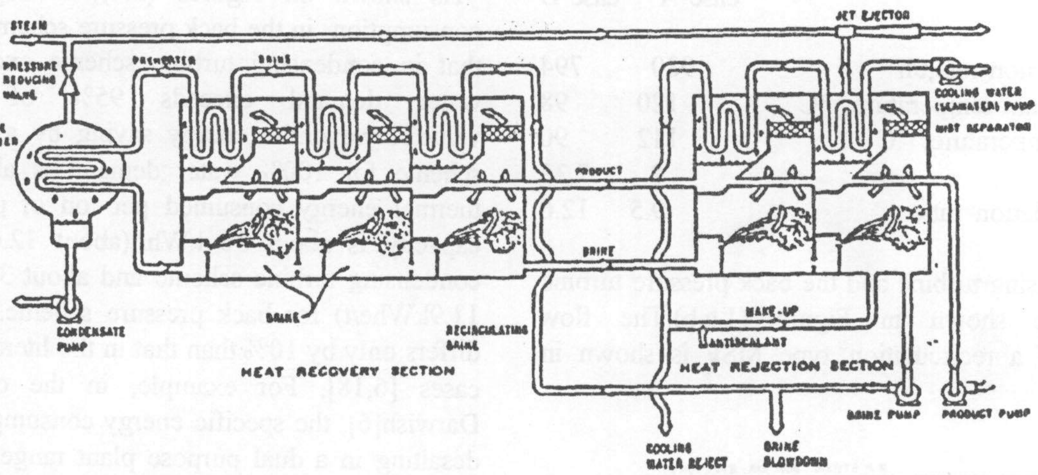

Figure 2. Typical flow schematic of brine recirculation MSF plant (Courtesy of Sasakura).

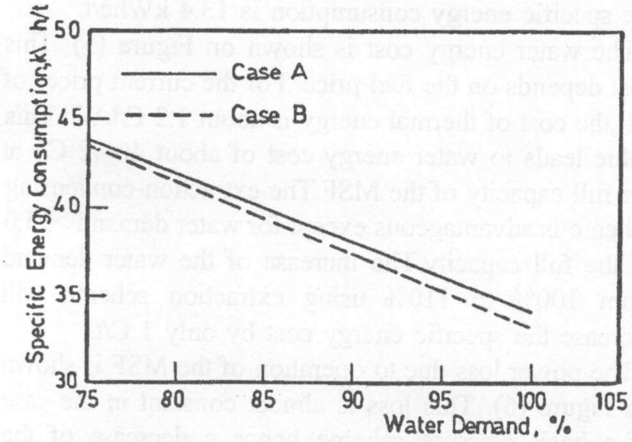

Figure 3. Specific energy consumption for back pressure turbine scheme.

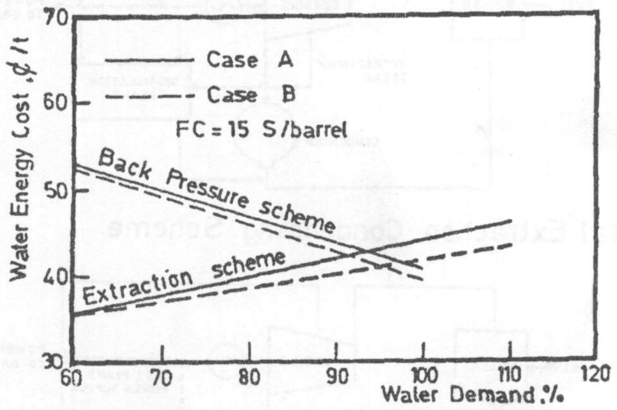

Figure 5. Water energy cost for back pressure and condensing turbine schemes based on specific energy consumption.

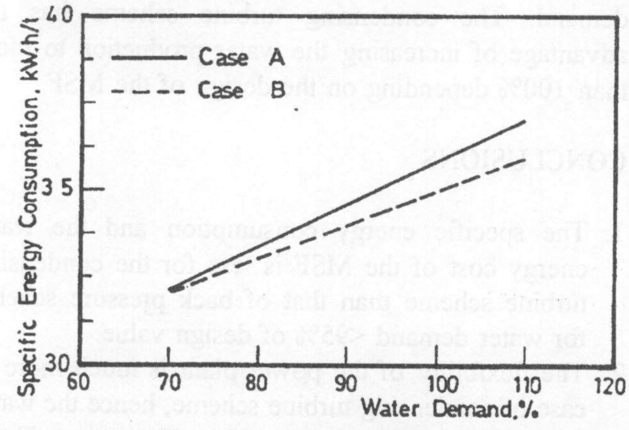

Figure 4. Specific energy consumption for extraction-condensing turbine scheme.

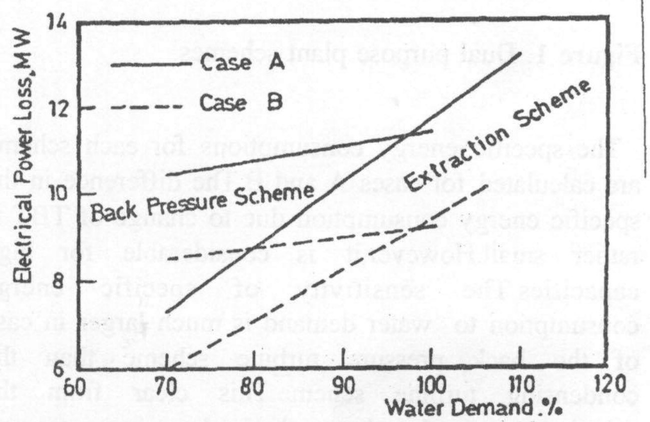

Figure 6. Electrical power loss due to operation of MSF with different conditions based on specific energy consumption.

Nomenclature

FC	fuel cost,/kg or \$/barrel
HHV	high heating value ,kJ/kg,
h	steam enthalpy, kJ/kg,
m	mass flow rate, kg/h,
Q	rate of energy consumption, kJ/h or kWh
R	gain ratio,
T	temperature, °C,
TBT	top brine temperature, °C,
ΔP	pressure drop in the recirculation pump,N/m^2
ΔS	increase in steam flow rate,kg/h,
η	efficiency
ρ	density,kg/m^3

Subscripts

b	boiler
c	condenser
d	desalted water
e	extracted steam
f	feed water
h	hydraulic
m	mechanical
r	recirculated brine
s	steam
T	turbine
t	thermal

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